SOME APPLIANCES FOR THE ELEMENTARY STUDY OF PLANT PHYSIOLOGY.

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(WITH FIGURES 1–7.)

THE enlargement of the bounds of knowledge in any science, though primarily dependent on the researches of specialists, is greatly aided by a wide diffusion of their results through proper teaching. Thus are public sympathy and support enlisted, while the greater number of students attracted allows of wider selection and hence better material for the development of new investigators. This is all true of plant physiology, but at this particular time there is an additional reason for attention to it. Elementary botanical teaching is at present being improved to the point of reorganization, and the advance is chiefly in the direction of the study of the plant alive and at work, and of the interpretation of plant-structure through plant-function. This necessarily involves experimental plant physiology, the chief obstacles to whose wide introduction are the expense and difficulty of making it a laboratory study. The greatest service that can be rendered to the advancement of botanical teaching at the present time seems to me the invention of simpler, more manageable, less expensive and more logically conclusive experiments for demonstrating the most fundamental facts and principles of plant-physiology. This is as legitimate a subject for investigation as any other, and one whose difficulty and the ultimate scientific value of whose results give it no mean rank.

Most of the purchasable physiological appliances have been invented by investigators for obtaining results of a precise quantitative character, and are usually cumbrous, complicated, and expensive. An investigator can afford to use nothing less than the best, but in elementary teaching, where it is chiefly qualitative results that are sought, great simplification in appliances should be possible. No doubt when the stimulus of a wide use in teaching shall direct the proper combination of physiological knowledge and inventive skill more extensively in this direction, astonishingly simple ways of demonstrating important facts and principles will be found. Much has already been done along this line, but every teacher knows that many of the apparently simple experiments of the books are not actually practicable, nor do they always cover the more important topics. Just here, indeed, lies the kernel of the whole matter; it is not only practicable experiments that are wanted, but experiments upon the most fundamental topics, absorption, transfer, transpiration, photosynthesis, respiration, growth, irritability. One good experiment upon such themes is worth many upon minor ones. No doubt the subject will ultimately work itself out for elementary classes in much the same way that it has already done in physics, namely, in the form of a standard series of a dozen or fifteen experiments on the leading topics, the apparatus for which will be purchasable at a fair cost from supply companies.

The appliances here to be described have been developed in the author's courses in Smith College. Every piece has been many times tried and is known to be practicable.

1. A temperature stage.

The response of protoplasmic movement to variations of temperature, even if not a topic of much importance in itself, is worth studying as a fine example of quantitative response to external influences, and especially as an introduction to the exact statistical method of studying physiological phenomena. It is not, of course, for beginners, but for those of middling grades. For this work a temperature stage is necessary, preferably one for each student; but those on the market cost from $7 upwards. An efficient stage that can be made by any plumber at small cost is shown in *fig. 1*. It is of sheet copper, one-sixteenth of an inch thick, of the breadth of a microscope stage, rolled over as shown by the figure to make a chamber for a thermometer and another for a three-inch slide, with holes for the light. Forward it dips down to enter a shallow (one inch deep) tin box which hangs from it by one cross wire and two stubs, as in the figure. Both stage and box taper forward to one inch and one and one half inches respectively, a feature not necessary though it diminishes leverage when the box is full. A battery clamp, properly filed, holds the apparatus to the stage of the microscope, and a mat of felt between prevents conduction of heat to it. The

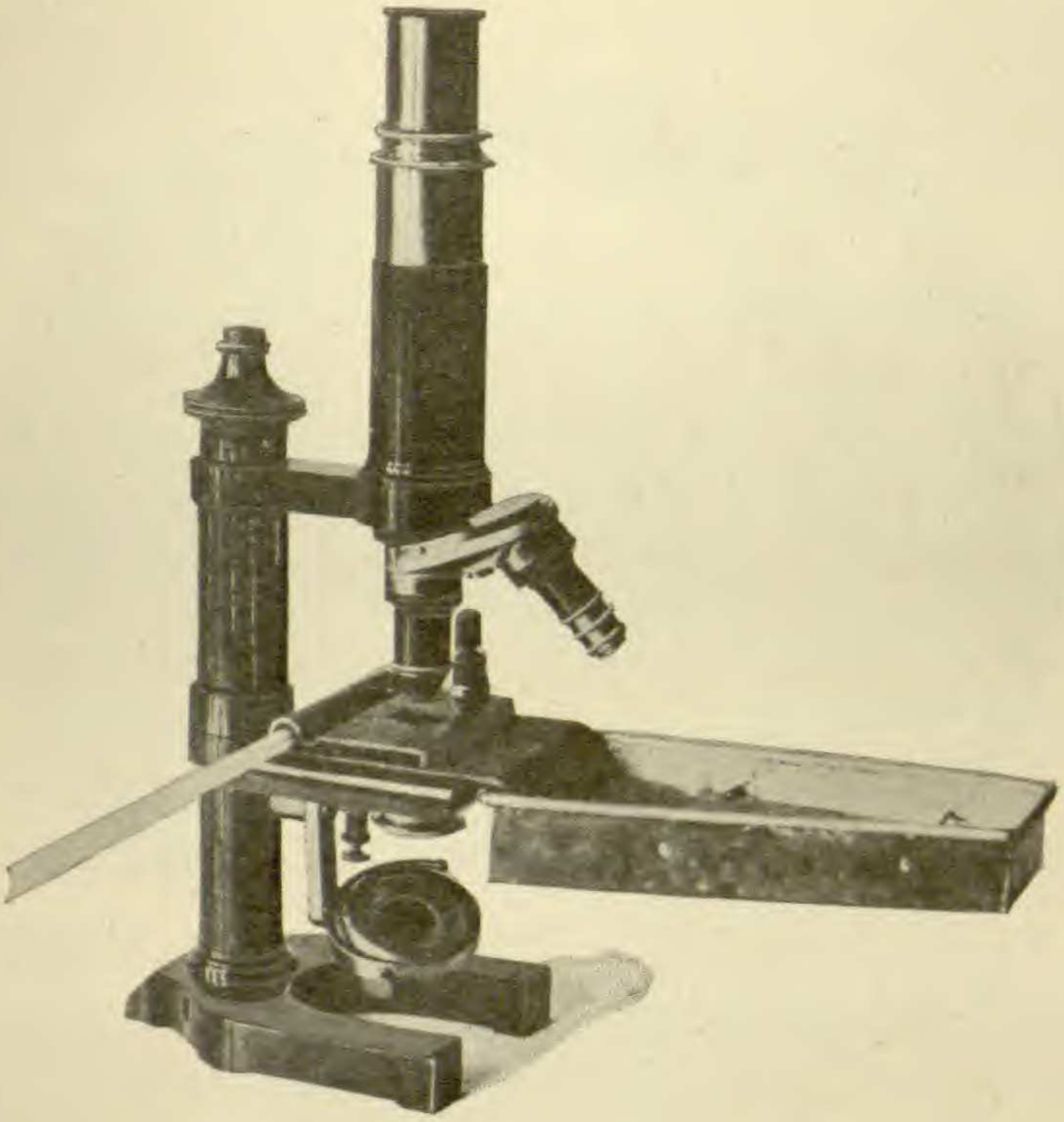

FIG. 1.—A temperature stage.

ordinary thermometers necessary for other purposes about a laboratory may be used, or bent ones, more easy to read, may be obtained at little advance over the straight kind. To raise the temperature, the box is filled with water and heated by a spirit lamp; to lower it, the box is filled with ice and salt. Every degree of temperature may thus be obtained, from below zero to boiling. If the student, observing stamen-hairs of Tradescantia or Nitella, uses an eyepiece micrometer and a metronome ticking seconds, the rate of movement under each degree of temperature may be obtained with the greatest nicety. The minimum, optimum, and maximum may be determined precisely, and all results tabulated and plotted in curves, an exercise of great pedagogic value to those beginning exact work in physiology.

It may be thought that the thermometer, being further from the source of heat than the slide, may register a lower temperature. This, however, is not appreciably so, as shown by one stage I had made with thermometer chambers both proximal

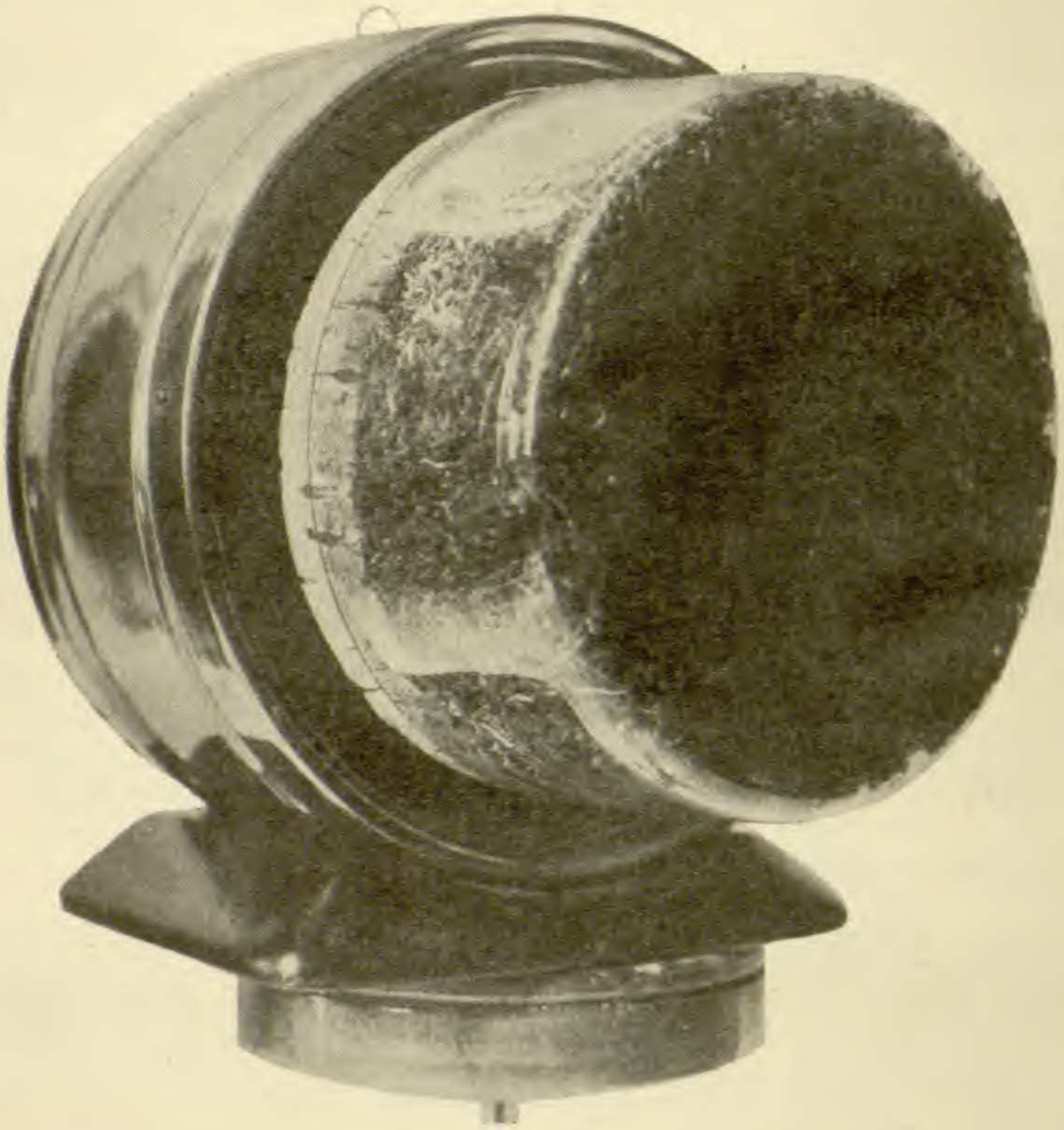

FIG. 2.—A clinostat.

and distal of the slide chamber. In this both thermometers registered practically alike unless the temperature was being raised with great rapidity, which is in any case not permissible because of its abnormal effects upon the protoplasm.

2. A clinostat.

It is most astonishing that so vastly important and illuminating a subject as irritability should receive so little attention as it does in our elementary courses. It is the clearness and ease with which this and some other fundamental biological phenomena may be illustrated in plants that makes botany, properly used, an indispensable factor for training in biology. Very much can be done in its illustration with no appliances at all, though for the satisfactory demonstration of some of its most important phases, a clinostat is necessary. The cheapest clinostat on the market is Wortmann's, costing $50, a very efficient instrument. Where, however, as in elementary work, it is the *principle* of geotropism or heliotropism that is to be illustrated, and not their manifestations in some particular plants or their parts, the arrangement shown in *fig. 2* is ample. A Seth Thomas eight-day clock is altered by a clockmaker so that its minute hand revolves once in fifteen minutes (to keep within ordinary reaction time).[1] The hands and surplus wheels are removed, and over the spindle thus left a brass sleeve is fitted, bearing at its outer end a thin brass disk, two inches in diameter, with a few holes in its edge, revolving in a plane parallel to the clock face. When the clock is horizontal this disk will carry a small flowerpot and when vertical it will carry also a considerable weight though hardly a pot. For illustrating geotropism, one takes two corks about five inches in diameter and an inch thick and pins to each of them soaked beans in the five different extreme possible positions; each is then covered with damp chopped sphagnum moss which fills a thin crystallizing dish of a size to cling to the beveled edge of the cork over which it is firmly pressed. The seeds should be brought out to the heads of the pins nearly an inch from the cork. One of the corks is now fastened to the brass disk by tacks put through the holes in the edge of the latter and is kept revolving in a vertical plane on the clinostat. The other near by, under the same external conditions, is kept fixed in one position. In three days the results are most instructive, and, indeed, this experiment leaves nothing to be desired in the beauty of its illustration of this particular subject.

[1] I believe that in my instrument this was accomplished partly by shortening the hair spring, and partly by removing each alternate tooth from the escapement wheel.

The best beans I have found for the purpose are horse beans, which are little liable to mold, while chopped sphagnum moss is the best medium I have found for growing seeds in almost any physiological experiments. The entire apparatus costs less than ten dollars.

3. A self-recording auxanometer.

The study of growth in the higher plants, and of how it is influenced by external conditions of light, temperature, moisture, etc., is always an important topic in an elementary course, and for it a self-recording auxanometer is needed. Many forms have been devised, but none has come into general use, except the well-known Albrecht form, which costs over $100. I have made a fair instrument, shown in *fig. 3*, constructed as follows: Take a dollar clock and remove hands, face and all surplus wheels, which will leave a round steel spindle three-fourths of an inch long projecting above the works. Have turned on a lathe a hardwood cylinder, twelve inches long and an inch in diameter, with a hole turned in one end truly in the center, a little smaller than the steel spindle of the clock. The cylinder is then forced down on the spindle and stands vertically and firmly, revolving once an hour. Have turned also on a lathe a double wheel as shown in the figure, the larger as thin as possible, six inches in diameter, grooved on the edge, and the smaller an inch in diameter, the whole carefully and lightly varnished with shellac to prevent warping. Through the axis of this double wheel a small smooth hole is turned on the lathe, and by this hole the wheel turns on a clean new fine needle soldered horizontally to a firm support. The wheel will revolve on the needle with very slight friction. A fine silk thread carefully and finely waxed (to prevent hygroscopic absorption of water) is attached in the usual way to the tip of a vigorously growing part (such as a flower stalk of hyacinth), run several times around the small wheel, and fastened by a tiny drop of glue. A similar thread is run in reverse direction around the large wheel twice and fastened. The other end carries the pen against the cylinder. The pen is made from a piece of small glass tubing sharply bent so that both ends press against the cylinder, one end being open and smoothed and the other drawn out to a capillary point bent to press at right angles against the cylinder.[2] It is then partly filled with chronograph ink. The cylinder is covered with thin smooth paper put on moist with one edge gummed down so that when dry it is without wrinkles. Enough weight is added to the pen to make the wheel turn as the plant grows, and as growth occurs the pen descends, tracing on the paper a spiral line. If now a vertical line be ruled on the cylinder, the length of the parts intersected by the spiral line will give the exact growth per hour, of course magnified. If half-hour intervals are needed, another line is ruled 180° from the first, and the paper between the two removed on one side, when the edges may be brought together, giving half-hour intervals. Of course these records may be removed from the cylinder for preservation. There may not be room for pot and clock under the wheel and either they must be put upon different levels, or else the thread from the plant must be run through a fine screw eye or other smooth arrangement as shown in the figure. This instrument is liable to the same errors as

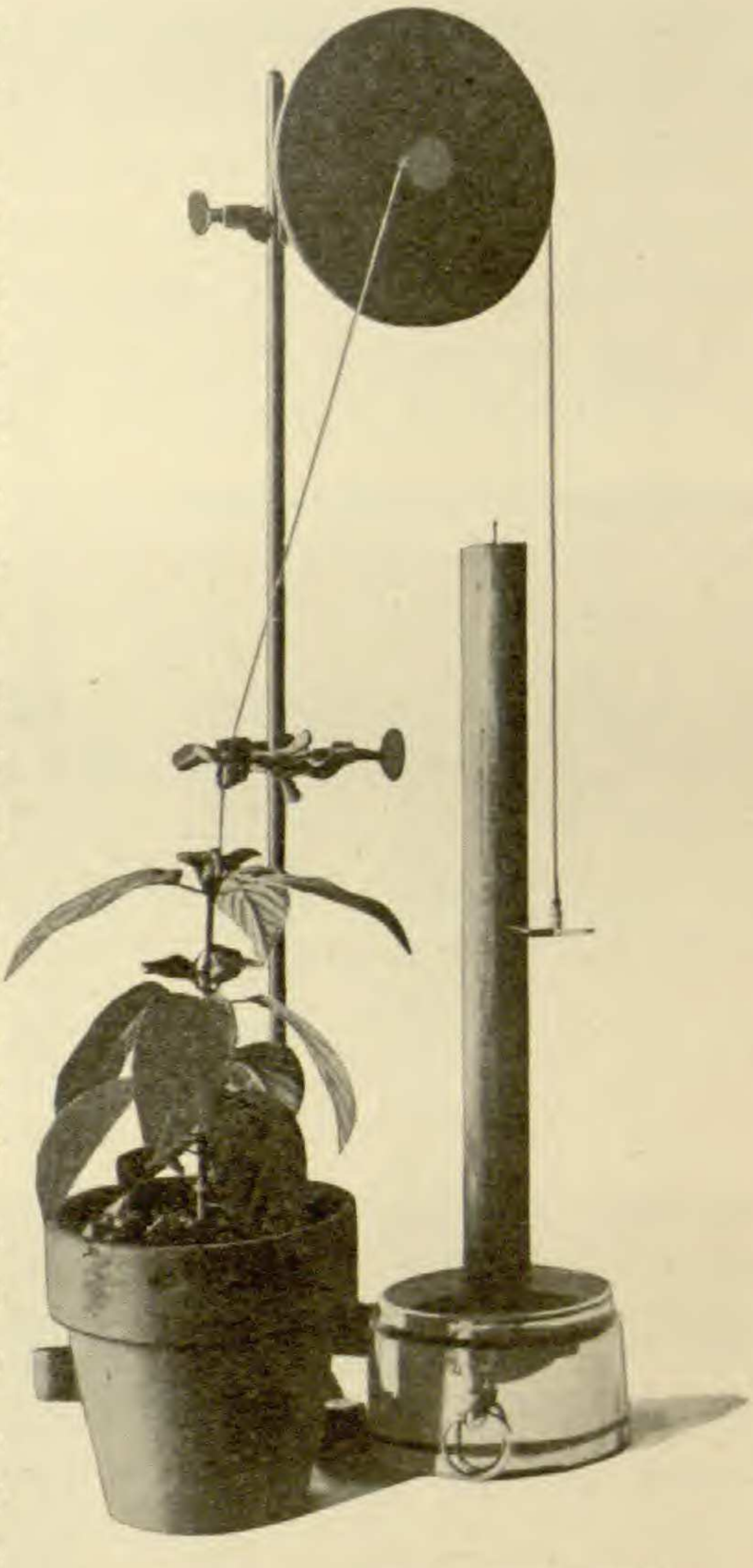

FIG. 3.—A recording auxanometer.

[2] The figure shows an earlier and less efficient pen.

the Albrecht, but with large vigorous plants it gives results which, if not exact, are sufficiently so to be very instructive to beginners. It need not cost much over $2.

4. An osmometer.

The absorption of water by roots cannot be omitted from an elementary course, and osmosis must be demonstrated, necessitating some form of osmometer. A most efficient one is the following: Cut off an ordinary burette about 2cm below the beginning of the graduation and smooth the end in the flame. Over it push for a centimeter or more a soaked Schleicher and Schüll diffusion shell of 16mm diameter,[3] which will fit the burette exactly, and tie it very tightly with several turns of waxed thread. Fill shell and burette up to the zero mark with molasses, and immerse the shell in pure water. The rise of the liquid will be very pronounced and rapid, and may be measured on the graduated tube.

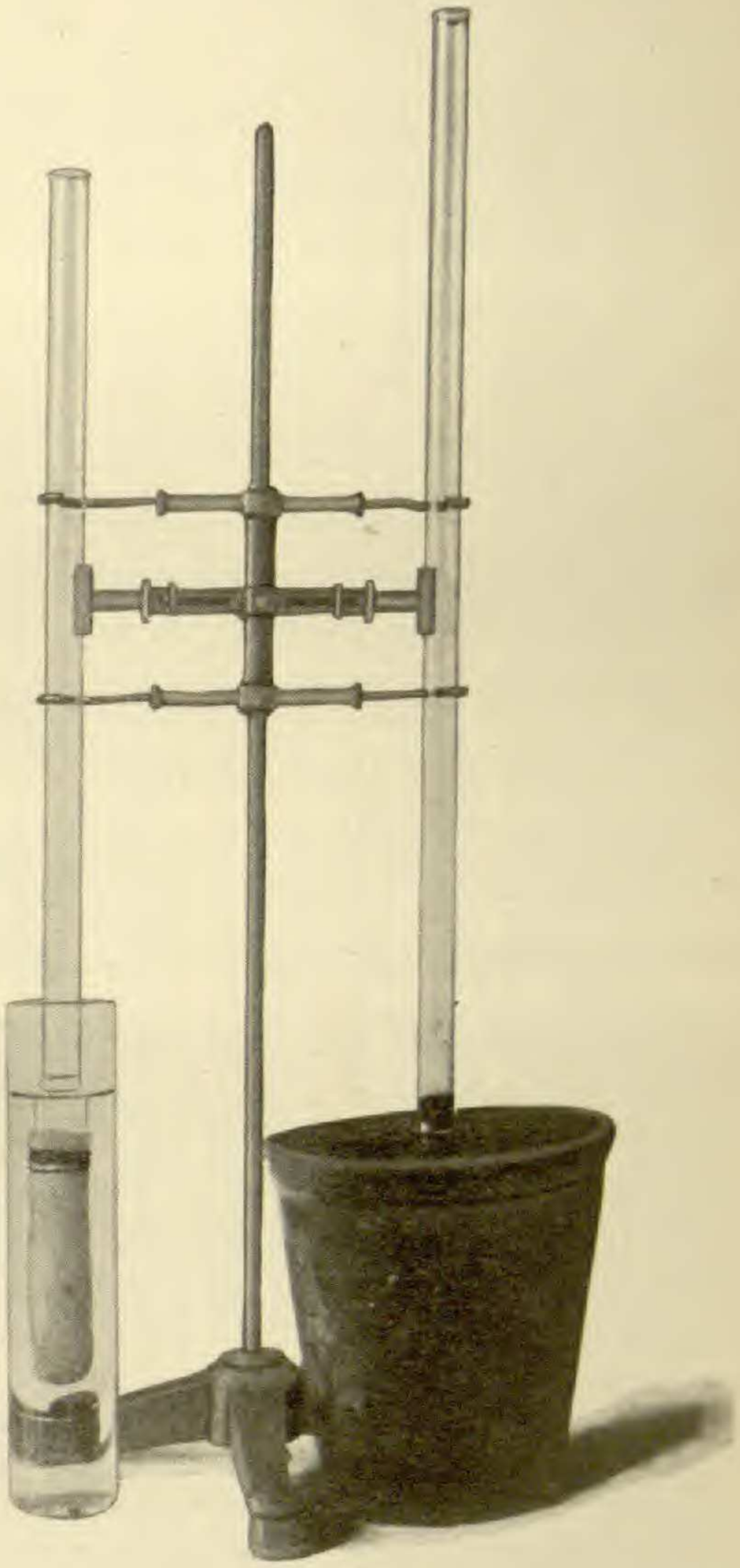

FIG. 4.—An osmometer.

This experiment is most instructive when performed along side of another in which a similar burette is attached by rubber tubing to the cut stump of a vigorous plant with a stem about the

[3] These may be obtained at a low cost from Eimer and Amend, New York.

diameter of the burette. The water will rise vigorously. We then have side by side two similar burettes, to one of which innumerable tiny absorbing hairs are attached, and to the other a single huge one. It is true there is the difference between them that the root hairs have a semi-permeable lining of protoplasm absent from the shell, and that they do not open directly into tubes as the shell does, but these differences are of minor account in comparison with the fact that it is fundamentally the same physical force that produces the absorption in the two cases.

5. A respiration apparatus.

Of prime importance in plant physiology is the exchange of gases in the processes of respiration and photosynthesis. It is

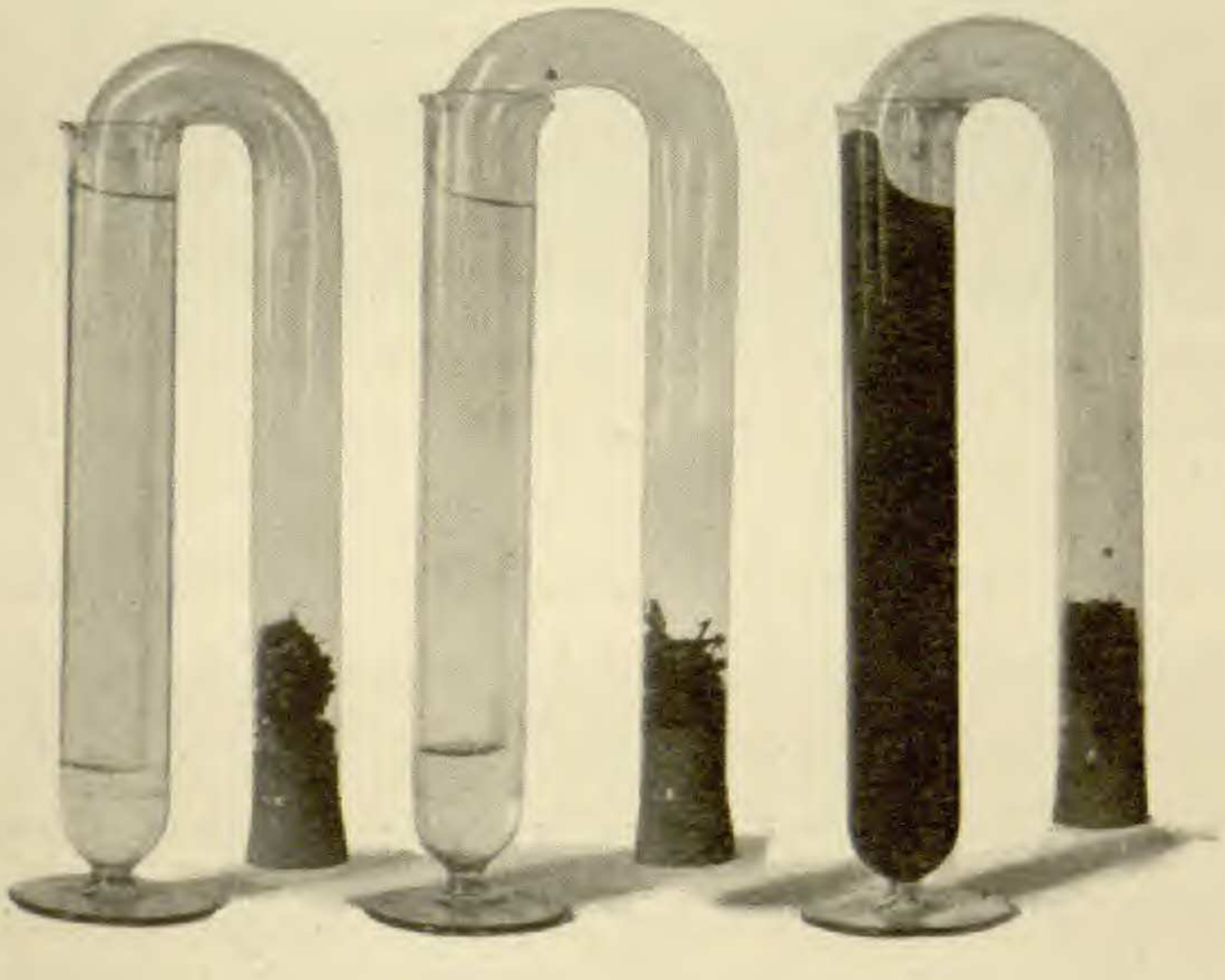

FIG. 5.—Respiration apparatus.

the more important in elementary courses, since nearly everybody, with the reciprocal exchange between animals and plants in mind, fails even to recognize that respiration exists in plants. It helps greatly to clear a student's mind on this subject if the nature and importance of respiration are made plain to him before he has had a chance to confound its processes with those of photosynthesis. The germination of seeds offers a good chance to demonstrate the gas exchange in respiration uninfluenced by that in photosynthesis, and it may logically be demonstrated as follows:

Take three test tubes on feet (*fig. 5*) or their equivalent, and fill each half full of, respectively, (1) pure water, (2) strong caustic potash, (3) mixture of concentrated caustic potash and pyrogallic acid. Take three U-tubes of somewhat smaller diameter than the test tubes, and in one end of each place about twenty soaked fresh radish seeds, or else a few soaked oats, placing under each lot a wad of moist sphagnum, and shut them in by a tight rubber cork. The other ends of these tubes are to be placed in the three test tubes. It will be found after a few hours that the pyrogallic mixture had risen in the U-tube about one fifth of its length. This is because it has absorbed the oxygen, and it is the most convenient way to get rid of oxygen from a small space. These seeds do not germinate, or only very slightly (probably from intramolecular respiration, though possibly because not all of the oxygen has been removed). In the tube with the potash, in a day or two, the liquid has risen to about one fifth of the length of the U-tube, and the seeds have germinated. The rise is of course due to the absorption by the potash of the carbon dioxide given off by the germinating seeds. In the tube with the water the liquid rises but little though the seeds germinate freely. This part of the experiment is necessary in order to prove that it is not simply the absorption of the oxygen that allows the liquid to rise in no. 2, but that an equivalent volume of another gas is given off.

This experiment logically proves, (1) that oxygen is necessary to growth; (2) that oxygen is absorbed in growth; (3) that carbon dioxide is given off in growth; (4) that oxygen absorbed and carbon dioxide given off in growth are equal in volume. Thus is respiration demonstrated.

In setting up the pyrogallic tube it is practically best to place the pyrogallic acid in the end of the U-tube and the concentrated caustic potash in the test tube. U-tubes, instead of straight tubes with the seeds at the upper end, are best, because in the latter case moisture runs down from the wet seeds and potash diffuses up the streams and kills the seeds.

6. A germination box.

A student's introduction to botany is best made through the study of living plants that are doing something characteristic. Practically it is difficult, and in city schools generally impossible, to make such studies out of doors, and the best substitute I know of is to provide each student at the start with seeds whose germination and growth he can watch. Of course these can be grown in pots or boxes, in sawdust, cotton wool, etc., but after much trial I have found a germination box like *fig. 6*,

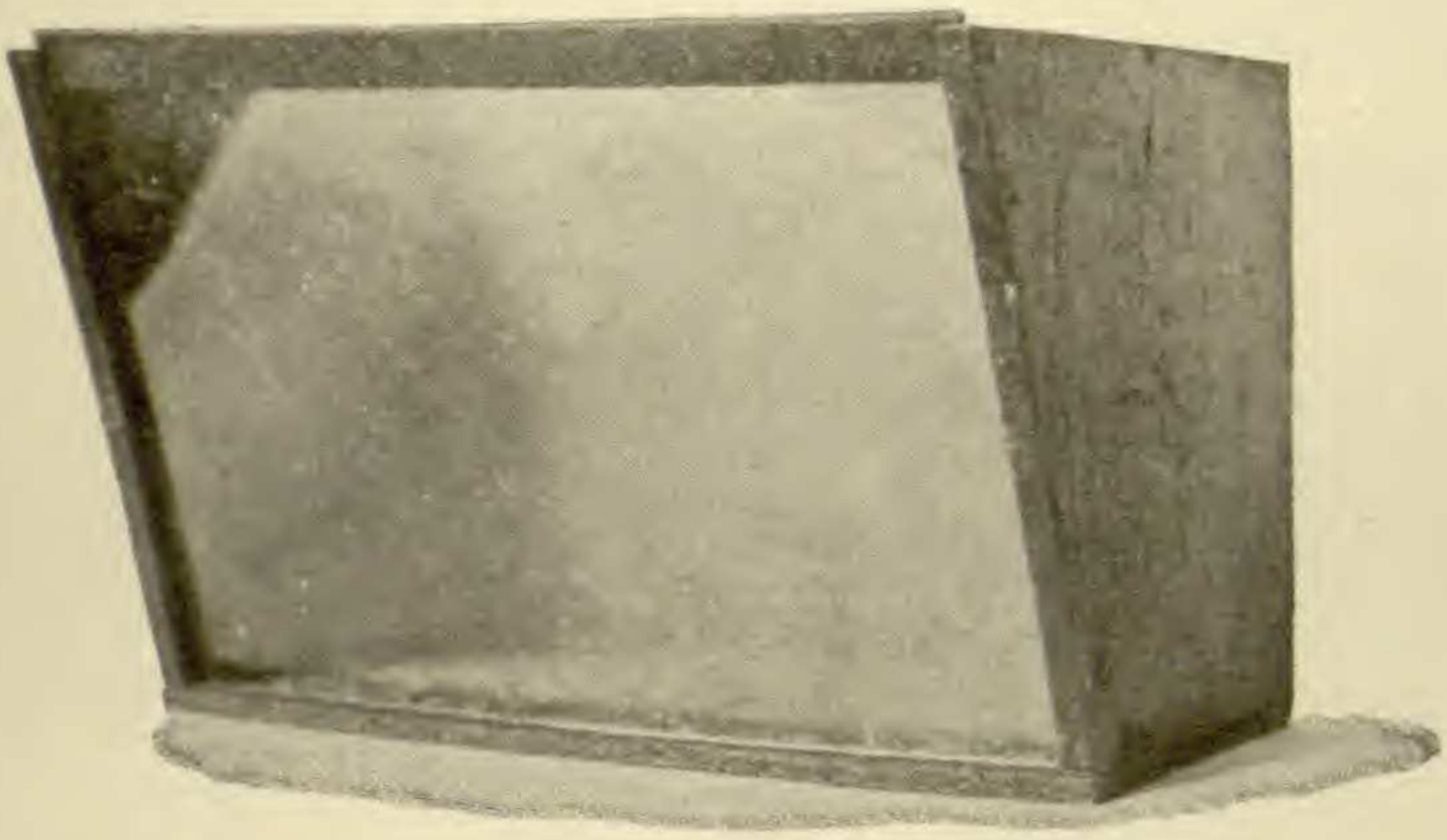

FIG. 6.—Germination box.

filled with chopped sphagnum moss, the best apparatus. It is eight inches in length by six in extreme breadth and five in depth, with a sloping glass side slipping into a groove. The rough edge of the glass is protected by a strip of wood, as shown in the figure. These boxes are made in quantity at box factories for eight cents each without glass, and cost not over twelve cents each complete. When well painted they may be used many years in succession. The great advantage of the sloping glass side is that it allows the roots to be studied, not only the tip, hairs, and branching, but also their geotropic positions. The latter are particularly instructive when the glass is tipped in the same plane through 45°. In fact, the box is practically that used to such profit by Sachs. The sphagnum not only permits the seeds to grow well, in this being the best medium I know, but it allows them to be removed without injury to the roots, and it is very clean to work with. The student may keep the same box and follow development of the same seedlings for several weeks.

7. A transpiration device.

In preparing plants for transpiration weighings it is usual to wrap the pot in rubber cloth. This prevents the condition of the pot with respect to water being seen, and limits the supply of oxygen to the roots. If, instead, the pot be placed in a thin glass dish slightly larger in diameter than the pot, and one to two inches higher, it will be necessary only to roof it over with rubber, which is much easier than wrapping the whole plant; the condition of the soil may be seen and more or less water given as seems needed; and the oxygen supply for the roots is more nearly normal. Of course plant and glass are weighed together.

8. The graduation of roots, tubes, etc.

In experiments on growth and geotropism, one often needs to graduate roots, which is done with insoluble India ink. But when the ink is applied with a pen or brush, it generally runs and is very uneven in breadth of the lines. If a fine thread, kept stretched by the spring of a piece of wire, be used, and the ink placed on and allowed to soak into it, marks of perfect evenness and any desired breadth may be made by the thread. It is of course equally good for glass tubes. The thread and spring may be mounted conveniently in a needle-holder. A small frame could be made with threads 1^{mm} apart and parallel, with which a root could be graduated perfectly in one operation.

9. A root-pressure gage.

Root pressure is so important a subject that an efficient gage for its measurement is much needed. None, however, is available; the apparently simple S-shaped tube containing mercury, figured in most books, cannot be made to work without great difficulty. *Figure 7* shows a form which, while liable to some errors, yields, nevertheless, approximately correct results. A tube six inches or less long, with a good glass stop-cock at the top, is graduated, as just described, into convenient small divisions, and is then attached to a stump of a vigorous plant whose stem is about the diameter of the inside of the tube into which it slips a little. The attachment may be made by putting on the stump close to the glass a short piece of rubber tubing about as thick as the glass of the tube; a joint of larger rubber tubing is slipped over the glass and the smaller piece, and is then wound tightly with tire tape which will not yield to pressure from within. Such a joint will be pressure tight. A little water is poured into the tube with a pipette and brought to some zero mark. The stop-cock is then closed. As the water rises in the tube it will compress the air column, and the approximate amount of pressure exerted may be measured by Mariotte's law, *i. e.*, under constant conditions the pressure is inversely proportional to the volume of the air. Of course the successive readings should be taken as nearly as possible at the same temperature. The water vapor in the tube is a source of error, but not an appreciable one if the readings are taken at constant temperatures.

FIG. 7.—Root-pressure gage.

All manometer gages used for such purposes as this are liable to an error not always recognized, in that they assume the *quantity* of water available for exerting pressure to be unlimited, whereas in fact it is always limited. If the plant be small and the gage be large, the plant may not give off quantity enough to push the registering fluid up to the point which it should reach in order to register the true pressure under which the water actually is given off. Hence these gages are likely to register pressure more accurately the smaller they are.

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